11/12/93 15:35 ☎202 767 4988 AFOSR/NA

REPORT DOCUMENTATION PAGE

Dist: A

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	11/8/94 FINAL	Sept. 15, 1993 - Sept. 14, 1994

4. TITLE AND SUBTITLE
RESEARCH INSTRUMENTATION FOR POLYTECHNIC UNIVERSITY'S SUPERSONIC WIND TUNNEL FACILITY

5. FUNDING NUMBERS
62228D
4276/AS
F49620-93-1-0588

6. AUTHOR(S)
Iraj M. Kalkhoran and M. Volkan Otugen

DTIC ELECTE FEB 0 1 1995 S D B

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Polytechnic University
Route 110
Farmingdale, New York 11735

8. PERFORMING ORGANIZATION REPORT NUMBER
POLY AE 94-02

AFOSR-TR- 95 0048

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NA
Dr. Len Sakell
AFOSR N/A
Bolling AFB, DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-93-1-0588

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimited

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 words)*

Modern instrumentation was acquired for use in Polytechnic University's Supersonic wind tunnel facility. The equipment is currently being incorporated in several on-going research projects dealing with development of non-intrusive measurement techniques, flow visualization, and pressure measurements in high speed unsteady flows. The major components of the research instrumentation include a Q-Switched ND: YAG laser, a CCD camera system with necessary hardware and software and a 16 channel data acquisition and control system with appropriate hardware and software. This report describes the basic function of the acquired equipment and the anticipated use of the equipment for conducting supersonic wind tunnel testing.

19950130 045

DTIC QUALITY INSPECTED 3

14. SUBJECT TERMS	15. NUMBER OF PAGES
Instrumentation, wind tunnel, supersonic flow	19
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
U	U	U	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

	Page
I. ABSTRACT	1
II. INTRODUCTION	2
III. DESCRIPTION OF EQUIPMENT	3
i. Q-Switched Nd:YAG Laser System	3
ii. CCD Camera System	3
iii. 16 Channel Data Acquisition and Control Unit	3
IV. IMPACT OF REQUESTED EQUIPMENT ON CURRENT RESEARCH	4
V. REFERENCES	5
VI. APPENDIX A: POLYTECHNIC UNIVERSITY'S SUPERSONIC WIND TUNNEL FACILITY	10

RESEARCH INSTRUMENTATION FOR POLYTECHNIC UNIVERSITY'S SUPERSONIC WIND TUNNEL FACILITY

by

Iraj M. Kalkhoran* and M. Volkan Otugen*
Department of Aerospace Engineering
Polytechnic University
Brooklyn NY 11201

I. ABSTRACT

Modern instrumentation was acquired for use in Polytechnic University's Supersonic wind tunnel facility. The equipment is currently being incorporated in several on-going research projects dealing with development of non-intrusive measurement techniques, flow visualization, and pressure measurements in high speed unsteady flows. The major components of the research instrumentation include a Q-Switched Nd:YAG laser, a CCD camera system with necessary hardware and software and a 16 channel data acquisition and control system with appropriate hardware and software. This report describes the basic function of the acquired equipment and the anticipated use of the equipment for conducting supersonic wind tunnel testing.

* Assistant Professor

II. INTRODUCTION

The national importance of the development of effective long-range supersonic transport, high performance agile supersonic fighter aircraft, tactical missiles of the next generation, and the ranking of air-breathing propulsion as a critical technology in several federal agency evaluations underscore the need for appropriate educational and research tools. Among these are flexible wind tunnel facilities with capability for rapid response to technological needs. Unfortunately, the expense associated with capital facilities, uncertainty of continuity of support for operation, and the present industrial restructuring have forced the shutdown of a number of facilities. Recognizing the long-term need for supersonic experimentation training and research, Polytechnic University decided to go forward with a program of updating and expanding their high speed facilities. We have recently replaced our fixed-block Mach 3, 10" x 10" wind tunnel with a variable Mach 1.75-4.0, 15" x 15" wind tunnel facility[1].

The new facility is an intermittent blow-down wind tunnel and is capable of producing unit Reynolds numbers in the range of 8×10^6 to 66×10^6. The wind tunnel was initially part of the Fairchild/Republic aerotest facility and more recently was owned and operated by the Grumman Corporation in support of its supersonic research and development programs. A schematic drawing of the facility is shown in Fig. 1 and performance characteristics of the tunnel is presented in Fig. 2. Appendix A describes the new supersonic facility and its capabilities for the research needs of the University. The wind tunnel facility has an exceptionally good flow quality suitable for conducting production type tests as demonstrated by flutter and F-14 inlet tests as large as 1/7 scale when operated by Grumman.

In order to fully utilize the unique capabilities of the wind tunnel for conducting supersonic experimentation, research instrumentation for accurate flow diagnostics with particular emphasis on laser-based, non-intrusive techniques were acquired. The primary objective of this effort was to acquire instrumentation necessary to develop and implement advanced laser-based diagnostic techniques and a data acquisition and control system for use in Polytechnic University's 15" x 15" supersonic wind tunnel facility. The laser-based instrumentation acquired is currently being used to develop and implement a Rayleigh scattering technique for the measurements of instantaneous density and velocity field and planar visualization of supersonic flows containing complex wave structures. Currently, the acquired equipment is being used to develop a spectrally resolved Rayleigh scattering method for instantaneous velocity measurements. The measurement systems developed will be continually used in aerodynamic test facilities for emerging research topics. The data acquisition and control unit acquired is currently being used for instantaneous measurements of flow properties in unsteady flows requiring fast sampling frequencies.

III. DESCRIPTION OF THE EQUIPMENT

i. Q-Switched Nd:YAG Laser System

The Nd:YAG laser system is a Continuum Powerlite 9010 series equipped with second, third and fourth harmonic generating crystals for green (visible; 532 nm) and uv (354.7 nm and 266 nm) operation. In addition, the laser is equipped with a diode laser for injection seeding which enables the laser to operate at a single mode and thus at a single frequency. This feature of the laser will be used for the spectrally resolved Rayleigh scattering velocity measurements. With the injection seeding, the current Nd:YAG laser provides 2 J of pulse energy at 1064 nm fundamental frequency. The pulse energies for the second, third, and fourth harmonic frequencies are 1 J, 500 mJ, and 200 mJ respectively. The laser can be operated either in the single pulse or double pulse modes. A photograph of the laser system with its accessories is shown in Fig. 3.

ii. CCD Camera System

The acquired CCD Camera System is a Photometrics model AT200 designed for use in quantitative image acquisition systems. The CCD camera sensor is coated with Metachrome II for UV measurements and has a 1024 x 256 pixel resolution. The camera utilizes a cryogenically cooled detector head and is equipped with a controller card for computer interfacing. The system also has an image acquisition/analysis software. A photograph of the CCD camera and the detector head is shown in Fig. 4. An example of the function of the CCD camera during flow visualization of a wing tip vortex interacting with a normal shock wave taken in the Polytechnic University's supersonic wind tunnel facility at a test section nominal Mach number of 2.5 is shown in Fig. 5. The CCD camera is also being used as part of the spectrally-resolved Rayleigh scattering velocity measurement system. The optical technique utilizes a Fabry-Perot interferometer to analyze the spectrum of the Rayleigh signal. The peak shift is related to the velocity of the gas while the Doppler broadening of the Rayleigh signal is an indicator of the acoustic speed and hence the gas static temperature. The CCD camera analyzes the fringe system formed by the Fabry-Perot interferometer to provide the velocity and temperature information. A sample Fabry-Perot image acquired by the CCD camera is shown in Fig. 6.

Both the Nd:YAG laser and the CCD camera systems are currently being prepared for use in the AFOSR sponsored program for non-intrusive measurements of flow field generated during interaction of supersonic wing tip vortices and lifting surfaces.

iii. 16 Channel Data Acquisition and Control Unit

The system is composed of a LeCroy model 8025 instrument mainframe, LeCroy model 6810 four channel digitizers, LeCroy model 8901A GPIB instrument interface and appropriate hardware and software for computer interfacing. The integrated system has a 16 channel capability with data acquisition rate of up to 5 Ms/s. Installation of the system was recently completed and is currently being used to acquire pressure measurements in the supersonic wind tunnel facility. A photograph of the data acquisition/control unit is shown in Fig. 7.

IMPACT OF REQUESTED EQUIPMENT ON CURRENT RESEARCH

All the instrumentation described above is being or will be used in support of the AFOSR sponsored research program (Grant:F49620-94-1-0210) entitled "Experimental Investigation of Three-Dimensional Vortex-Airfoil Interaction in a Supersonic Stream". This research project involves interaction of wing tip vortices with a two-dimensional lifting surface in a supersonic stream. The interaction is generated by positioning an instrumented two-dimensional wedge section downstream of a semi-span, vortex-generator wing section so that the trailing tip vortices interact with the downstream surface. The experiments are designed to simulate interaction of for-body induced vortices with aft surfaces frequently encountered in supersonic flight of aircraft and tactical missiles. The investigation is designed to understand the physics of complex shock/vortex dominated flows and include influence of several aerodynamic and geometric parameters on the interaction.

The acquired flow diagnostics system is currently being incorporated in the supersonic wind tunnel facility initially for quantitative measurements of density in support of the above project and subsequently for single point time-resolved turbulent velocity measurements via a spectrally-resolved Rayleigh scattering technique which is simultaneously being developed. The impact of the instrumentation on the outcome of the research project are as follows. First, the planar Rayleigh scattering planned for the first phase of the study will provide an enhanced two-dimensional visualization capability superior to the existing shadowgraphic system. The planar laser-Rayleigh scattering technique will allow refined flow visualization capability which will result in <u>spatially resolved</u> two-dimensional interrogation of the flow. Such two-dimensional visualizations are not possible with traditional schemes incorporating Schlieren and shadowgraph techniques. For this purpose, slicing the flow using a laser light sheet will result in visualizing the density contours in the core of the vortex. In this manner, the laser light sheet can be used to visualize the vortex field both upstream and downstream of the interaction zone to detect any alterations to the vortex structure as a result of the encounter. The planar visualization of the of the flow field will be extremely useful in detecting the extent of vortex growth. For planar flow visualization purposes, the purchased laser system will be used to generate a thin sheet of laser light by expanding the beam with a cylindrical plano convex lens to illuminate a cross section of the flow field. The Rayleigh scattered light will be recorded by the CCD camera system allowing time-frozen two-dimensional flow analysis. This technique has been shown to be ideal for studies of vortex structure, vortex bursting, boundary layer profiles and shock waves in supersonic flows.

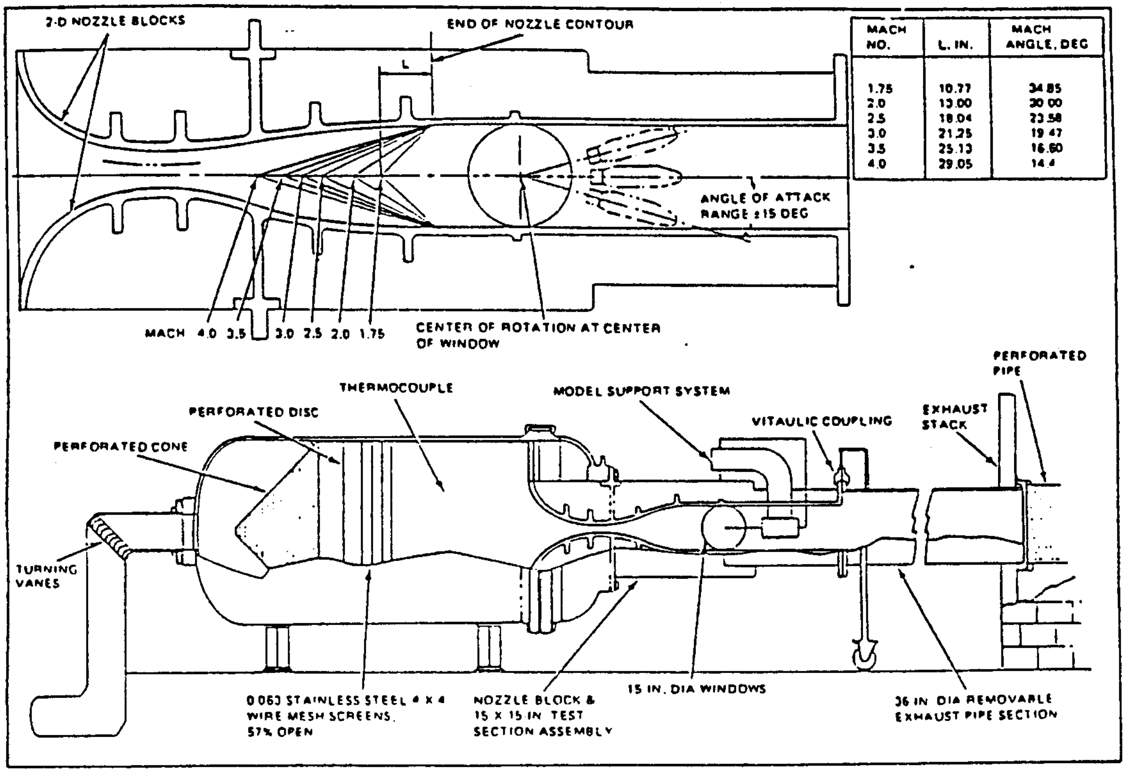
Next, the purchased equipment will be used as a single-point, time-resolved velocity probe this time using the spectrally-resolved interferometric Rayleigh scattering technique. This will allow the non-intrusive accurate measurement of velocity and the turbulence characteristics of the vortex flow.

An advantage offered by this system is its capability in providing quantitative measurements of flow properties without perturbing the natural flow environment. It is well established that conventional intrusive techniques for quantitative measurements of flow properties in a supersonic stream will adversely influence the flow and may result in inaccurate measurements of flow properties. With respect to this project, it is highly desirable to perform two-dimensional non-intrusive measurements of flow properties including velocity and density. A central objective of the project is to detect and establish criteria leading to a vortex breakdown with particular emphasis on development of a stagnation point and regions of reversed flow which is known to occur in incompressible vortex bursting. Incorporating a physical probe to detect such behavior is not desirable since a stagnation point will develop at the nose of the probe which will make it impossible to detect a natural stagnation point. The laser equipment acquired will enable us to perform such quantitative measurements. As stated above, the data acquisition and control unit is currently being used to detect unsteady features of the problem that were observed during the interaction.

In addition to the parent Grant, the acquired instrumentation will also be available to other faculty members of the university who are involved in experimental research activities. Since the purchased equipment are stand-alone, they could easily be adapted for use in other research facilities including subsonic wind tunnel testing, turbulence research, and shock tube testing. The useful life of the equipment are estimated to be on the order of 25-30 years. At present time, the Department of Aerospace Engineering has a highly trained dedicated technician whose responsibilities include maintaining all laboratory equipment . Much of our equipment and instrumentation has demonstrated considerable longevity and utility and departmental funds have been adequate to regularly upgrade instrumentation.

VI. REFERENCES

1. Kalkhoran, I., M., Cresci, R. J., and Sforza, P. M., "Development of Polytechnic University's Supersonic Wind Tunnel Facility," AIAA Paper 93-0798, January 1993, Reno, NV.



MACH NO.	L, IN.	MACH ANGLE, DEG
1.75	10.77	34.85
2.0	13.00	30.00
2.5	18.04	23.58
3.0	21.25	19.47
3.5	25.13	16.60
4.0	29.05	14.4

Fig. 1. Schematic Drawing of Polytechnic University's Supersonic Wind Tunnel

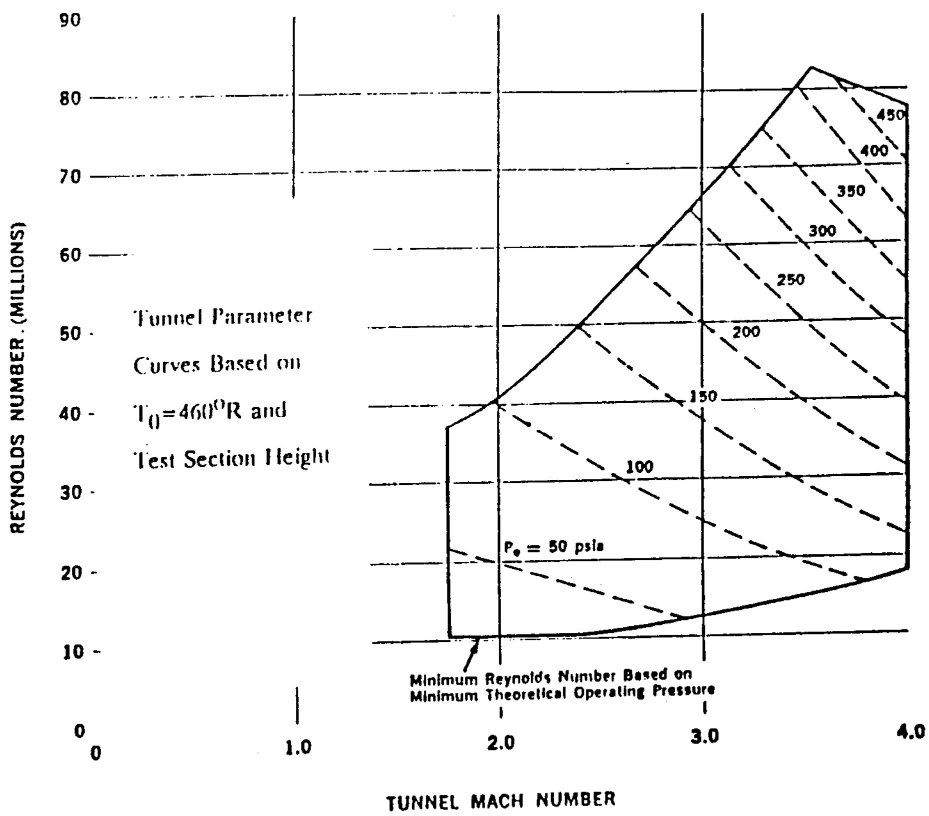


Fig. 2. Performance Characteristics of the Supersonic Wind Tunnel Facility

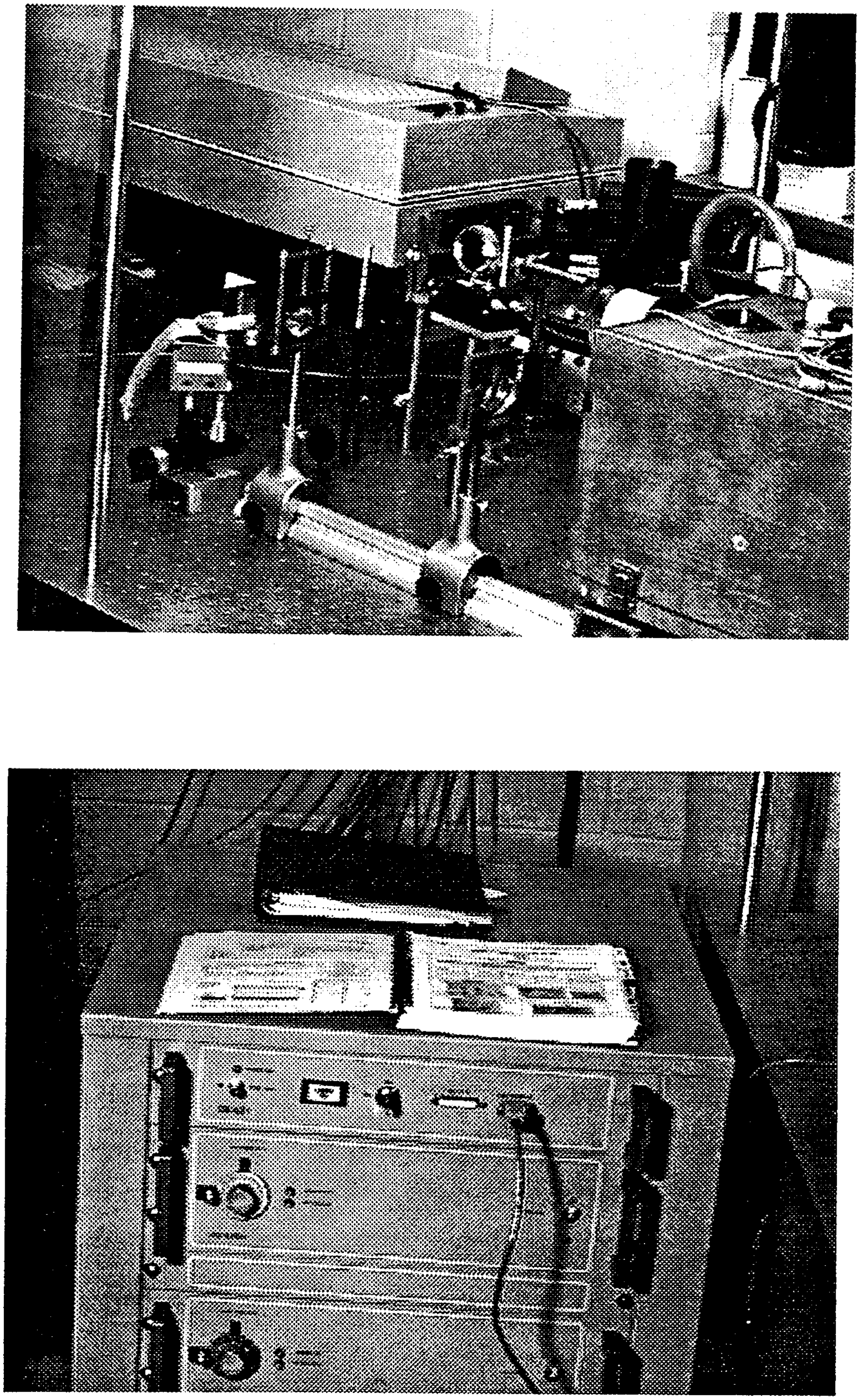


Fig. 3. Photographs of Nd:YAG laser and power supply

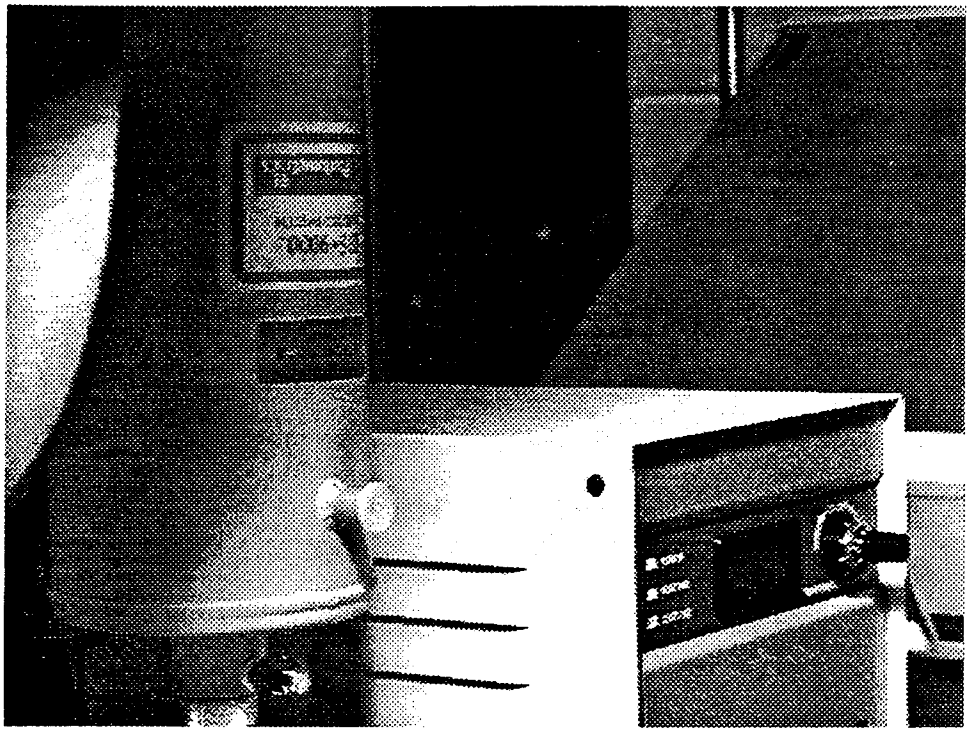


Fig. 4. Photometrics CCD Camera and Controller

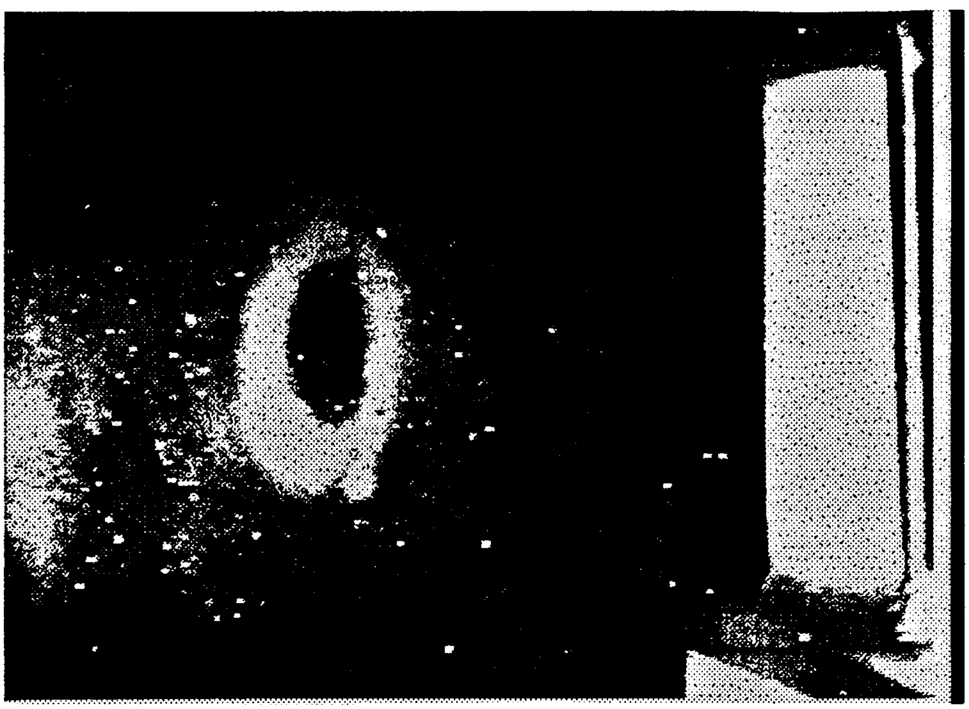


Fig. 5. A laser sheet visualization of the flow field during a normal shock wave vortex interaction utilizing the CCD camera system

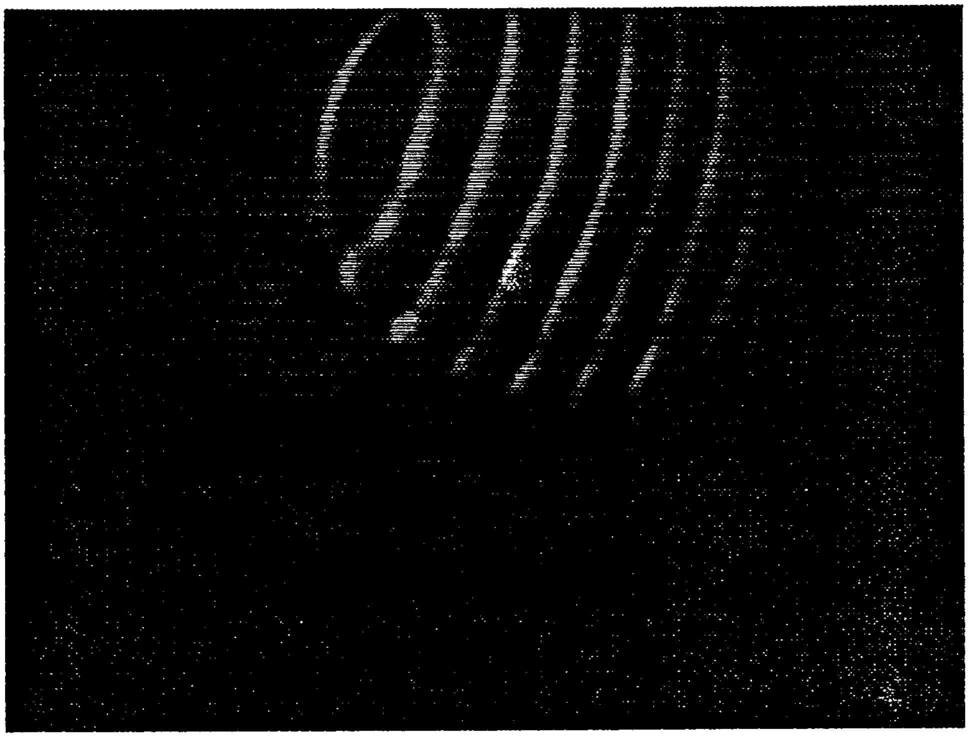


Fig. 6. Sample Fabry-Perot image acquired by the CCD camera

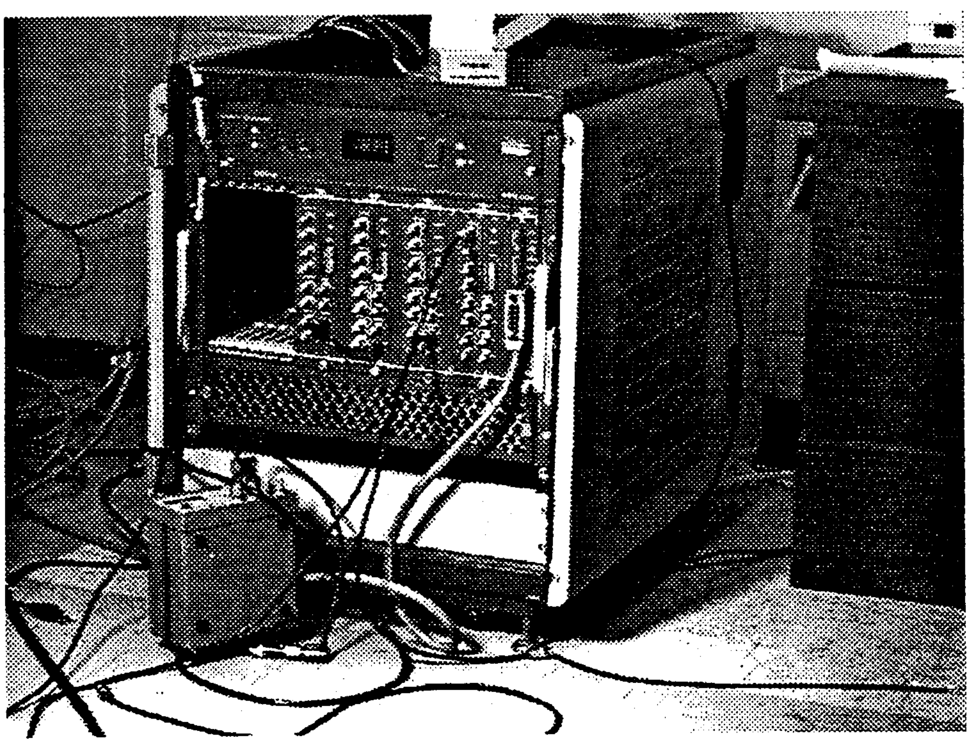


Fig. 7. Photograph of the LeCroy 16-Channel data acquisition system

APPENDIX A

POLYTECHNIC UNIVERSITY'S SUPERSONIC WIND TUNNEL FACILITY

POLYTECHNIC UNIVERSITY'S SUPERSONIC WIND TUNNEL FACILITY

The facility is an intermittent blowdown wind tunnel with a square test section of 38.1 cm x 38.1 cm (15 in x 15 in) and is capable of producing unit Reynolds numbers in the range of 26 x 10^6 to 22x10^7 per meter (8 x 10^6 to 66 x 10^6 per foot) over a Mach number range from 1.75 to 4.0. The tunnel utilizes fixed, contoured-nozzle-blocks to produce Mach numbers of 1.75, 2.0, 2.5, 3.0, 3.5 and 4.0. The wind tunnel is currently being used to conduct several projects dealing with supersonic vortex flows, vortex-fin interaction, and shock wave-vortex interaction.

The wind tunnel is located in the Preston R. Basset Research Laboratory which houses the research facilities of the Aerospace Engineering Department at Polytechnic University. This research complex is located at Polytechnic University's Long Island Center at Farmingdale, NY and includes offices for staff and students, a computer/control room, administrative offices, instrumentation laboratories, machine shop, wind tunnels and associated equipment. The Aerodynamics Laboratory facility consists of a high pressure air supply and storage system, various supersonic and hypersonic tunnels, vacuum pumping equipment, and a vacuum test chamber and storage sphere.

WIND TUNNEL DESCRIPTION

The supersonic tunnel is an intermittent blowdown facility exhausting to atmosphere. The facility was originally part of the Fairchild/Republic aerotest facility and, more recently, was owned and operated by the Grumman Corporation. A schematic drawing of the wind tunnel is shown in Fig. 1. The facility has a 38.1 cm x 38.1 cm (15 in x 15 in) test section (Fig. 2) and utilizes interchangeable contoured, precision machined, fixed supersonic nozzle blocks (Fig. 3) to produce Mach numbers of 1.75, 2.0, 2.5, 3.0, 3.5, and 4.0 with a contraction ratio from 25 at Mach 1.75 to 194 at Mach 4.0. Since the facility utilizes fixed-nozzle-blocks, two separate test section assemblies are available which permit rapid changes in nozzle and test set-ups. Access to the test section is via two round 38.1 cm (15 inch) diameter swing out windows (one on each side of the test section) used for flow visualization purposes (Fig. 2). The two glass windows may be replaced with solid plate inserts to permit the installation of a wall mounted model, if desired. The test sections have removable top, bottom, and side hatches; top and bottom hatches have expendable surface plates to which models may be attached.

Operation may be carried out over a stagnation pressure range of 0.17 Mpa to 3.4 Mpa (25 to 500 psia) to produce test Reynolds numbers in the range of 26-220 million per meter (8-66 million per foot) over a Mach number range from 1.75 to 4.0 (Fig. 4). The tunnel settling chamber (Fig. 5) is equipped with flow conditioners which consist of one 50% open conical and one 50% open flat perforated plate, in series with four

57% open screen banks. Such an arrangement results in good test section flow quality and low turbulence levels.

The tunnel uses a fixed exhaust diffuser which is not optimized to produce a decreased running pressure ratio. The overall tunnel starting pressure ratio for an empty test section varies from a low value of 1.6 at Mach 1.75 to a high value of 18 at Mach 4.0. The wind tunnel has been used to successfully conduct flutter and F-14 inlet tests as large as 1/7 scale when operated by Grumman.

THE AIR SUPPLY AND STORAGE SYSTEM

The supersonic wind tunnel facility is connected to Polytechnic University's air supply and storage system. Two Worthington four-stage compressors are available to pressurize the air to approximately 17 Mpa (2500 psia) at a pumping rate of 0.11 Kg (0.25 pounds) of air per second per compressor. The high pressure air leaves the compressors and flows through a system of separators which remove the oil and water vapor from the gas, and then through a system of silica gel driers which dry the air to a dew point below -40^{o}C. From the driers, the gas flows into the high pressure storage flasks and is available for utilization in the various tunnels. These flasks are manifolded into two banks of 25 tanks each; they are designed to operate at a pressure of 21 Mpa (3000 psia) although they are not pressurized above 15 Mpa (2000 psia) for routine tests. Each of the two banks has a volume of 28.3 m^3 (1000 ft^3) and can be put on the line either individually or together. The main supply line feeding the tunnels is connected by valves to the supersonic settling chamber, the heater for the hypersonic tunnels, and an additional small jet which can be used for subsonic mixing tests or for other types of facilities requiring low mass flow. A schematic diagram of the high pressure pumping, storage, and control valve system is shown in Fig. 6.

INSTRUMENTATION

Pressure transducers of variable reluctance, strain gauge, and quartz type are available for pressure measurements. Fast response quartz type transducers are used for unsteady flow diagnostics while variable reluctance and strain gauge types are used for routine steady state operations.

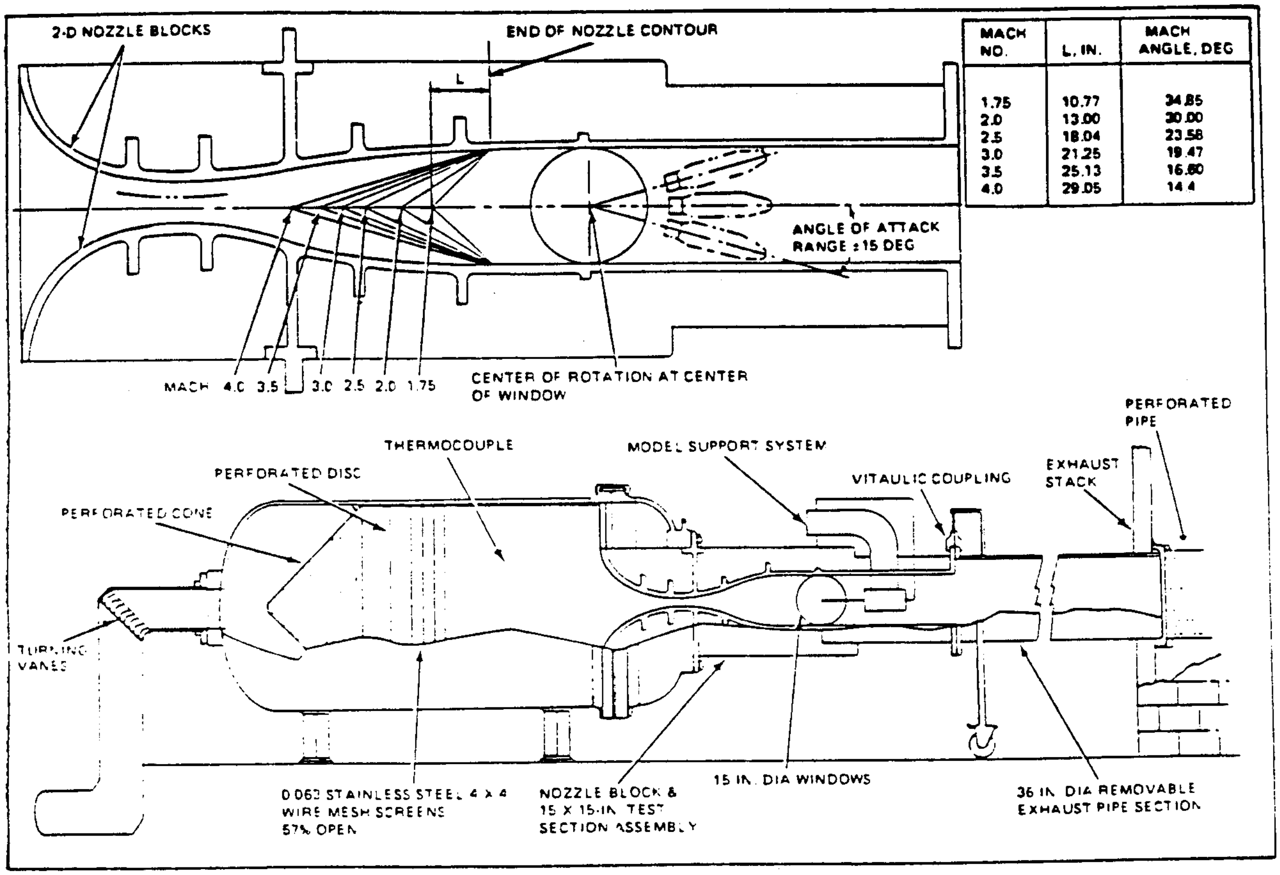
The pressure transducers and thermocouples are connected to a 26 channel amplifying and conditioning system from which they are fed into a 16-channel LeCroy Data Acquisition and Control System. The data acquisition system is composed of a LeCroy model 8025 instrument mainframe, LeCroy model 6810 four channel digitizers, LeCroy model 8901A GPIB instrument interface and appropriate hardware and software for computer interfacing. The integrated system has a 16 channel capability with data acquisition rate of up to 5 Ms/s. A photograph of the data acquisition/control unit is shown in Fig. 7.

Wind tunnel operation as well as data acquisition is carried out using an IBM PC/486-66 compatible computer system. During a typical run the raw data is stored in the digitizers on-board memory and then is transferred to the computer and hard disk for permanent storage. Through the commercial and customized software systems, the raw data is immediately available for viewing and subsequent reduction and analysis.

For non-intrusive measurement purposes a Nd:YAG laser system, an intensified CCD camera and a Monochrome Frame Transfer CCD camera are available. The Nd:YAG laser system is a Continuum Powerlite 9010 series equipped with second, third and fourth harmonic generating crystals for green (visible; 532 nm) and uv (354.7 nm and 266 nm) operation. In addition, the laser is equipped with a diode laser for injection seeding which enables the laser to operate at a single mode and thus at a single frequency. This feature of the laser is being used for the spectrally resolved Rayleigh scattering velocity measurements. With the injection seeding, the current Nd:YAG laser provides 2 J of pulse energy at 1064 nm fundamental frequency. The pulse energies for the second, third, and fourth harmonic frequencies are 1 J, 500 mJ, and 200 mJ respectively. The laser can be operated either in the single pulse or double pulse modes. A photograph of the laser system with its accessories is shown in Fig. 8. The CCD Camera System is a Photometrics model AT200 designed for use in quantitative image acquisition systems. The CCD camera sensor is coated with Metachrome II for UV measurements and has a 1024 x 256 pixel resolution. The camera utilizes a cryogenically cooled detector head and is equipped with a controller card for computer interfacing. The system also has an image acquisition/analysis software. A photograph of the CCD camera and the detector head is shown in Fig. 9.

An Aerolab 3-component sting balance as well as a 3-component wall-mount balance are available for force and moment measurements. A spark Schlieren/shadowgraph is presently available for flow visualization purposes. Design and installation of novel non-intrusive techniques for flow diagnostics, as well as laser-based visualization schemes are currently under way and will be implemented in the near future.

The facility is used to support educational and basic research activities of the department as well as being made available to the aerospace industry for developmental testing.



MACH NO.	L, IN.	MACH ANGLE, DEG
1.75	10.77	34.85
2.0	13.00	30.00
2.5	18.04	23.58
3.0	21.25	19.47
3.5	25.13	16.60
4.0	29.05	14.4

Fig. 1. Schematic of the supersonic wind tunnel facility

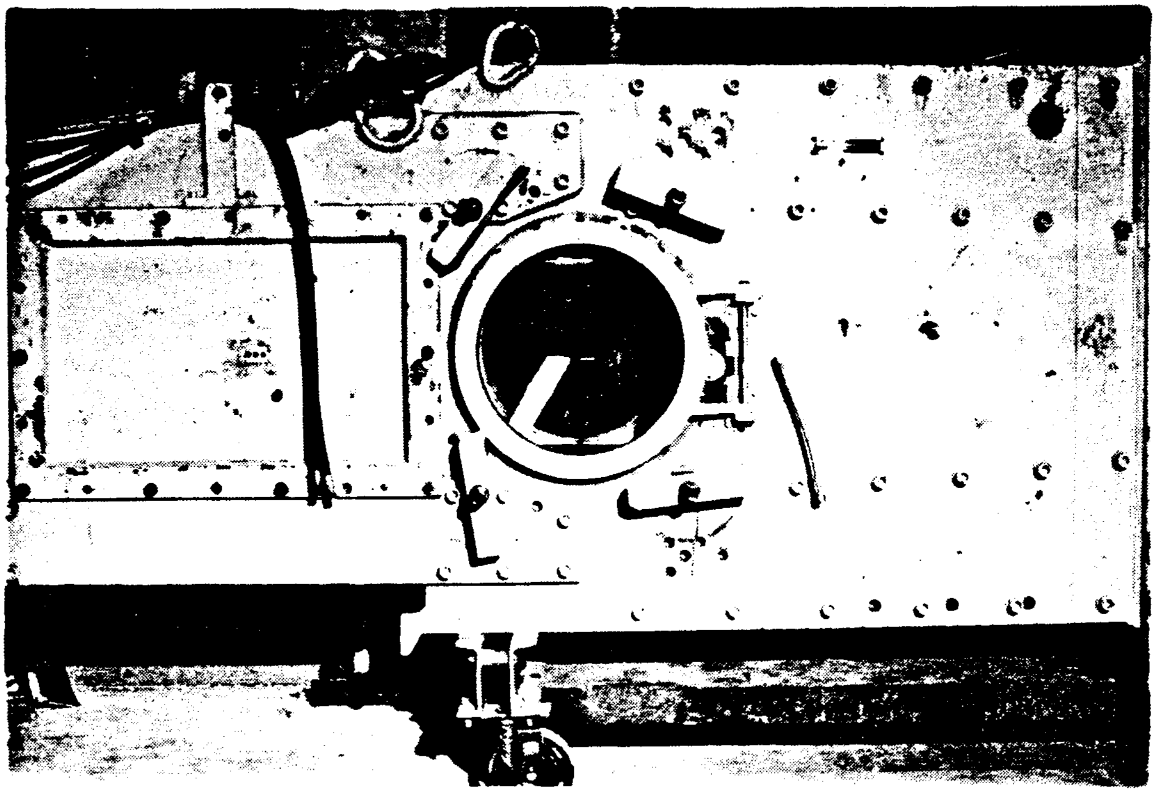


Fig. 2. Photograph of the wind tunnel test section

Fig. 3. Photograph of the nozzle blocks

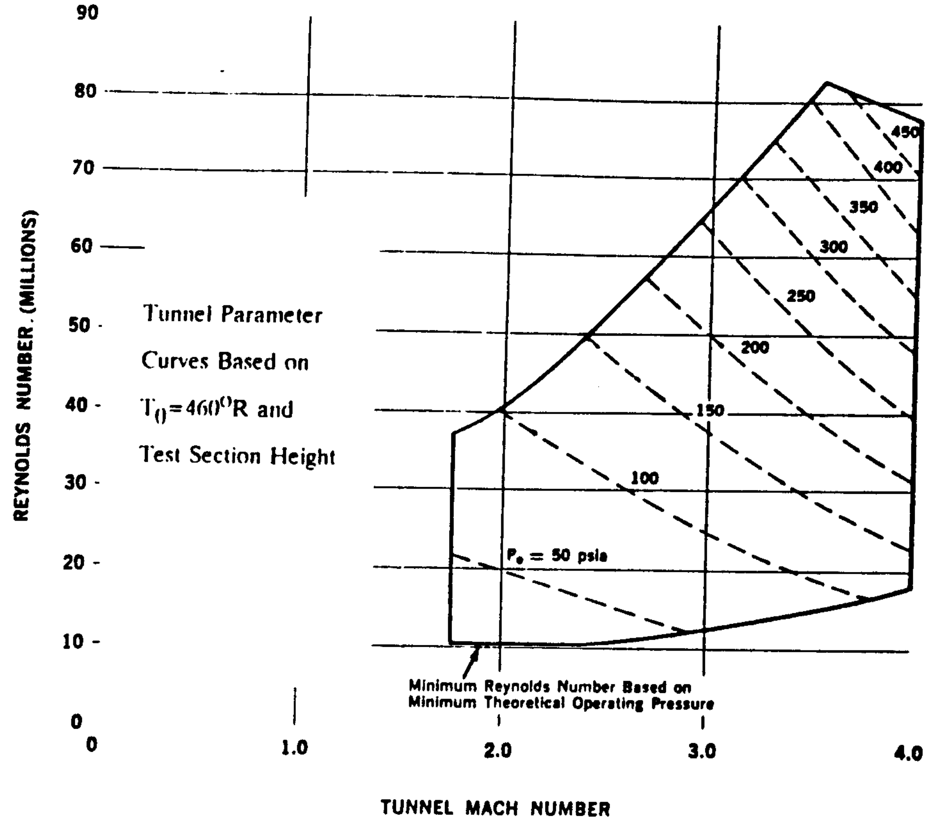


Fig. 4. Illustration of the wind tunnel performance characteristics

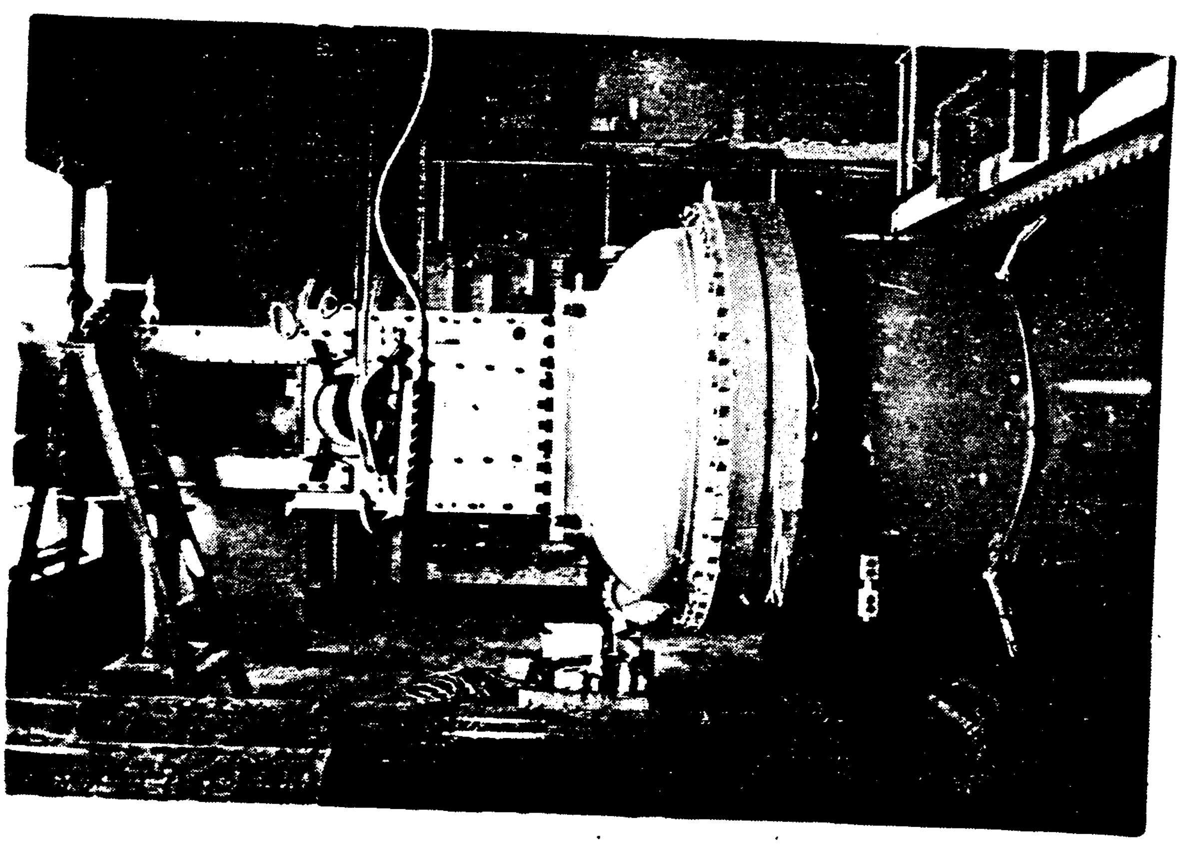


Fig. 5. Photograph of the test section and the settling chamber

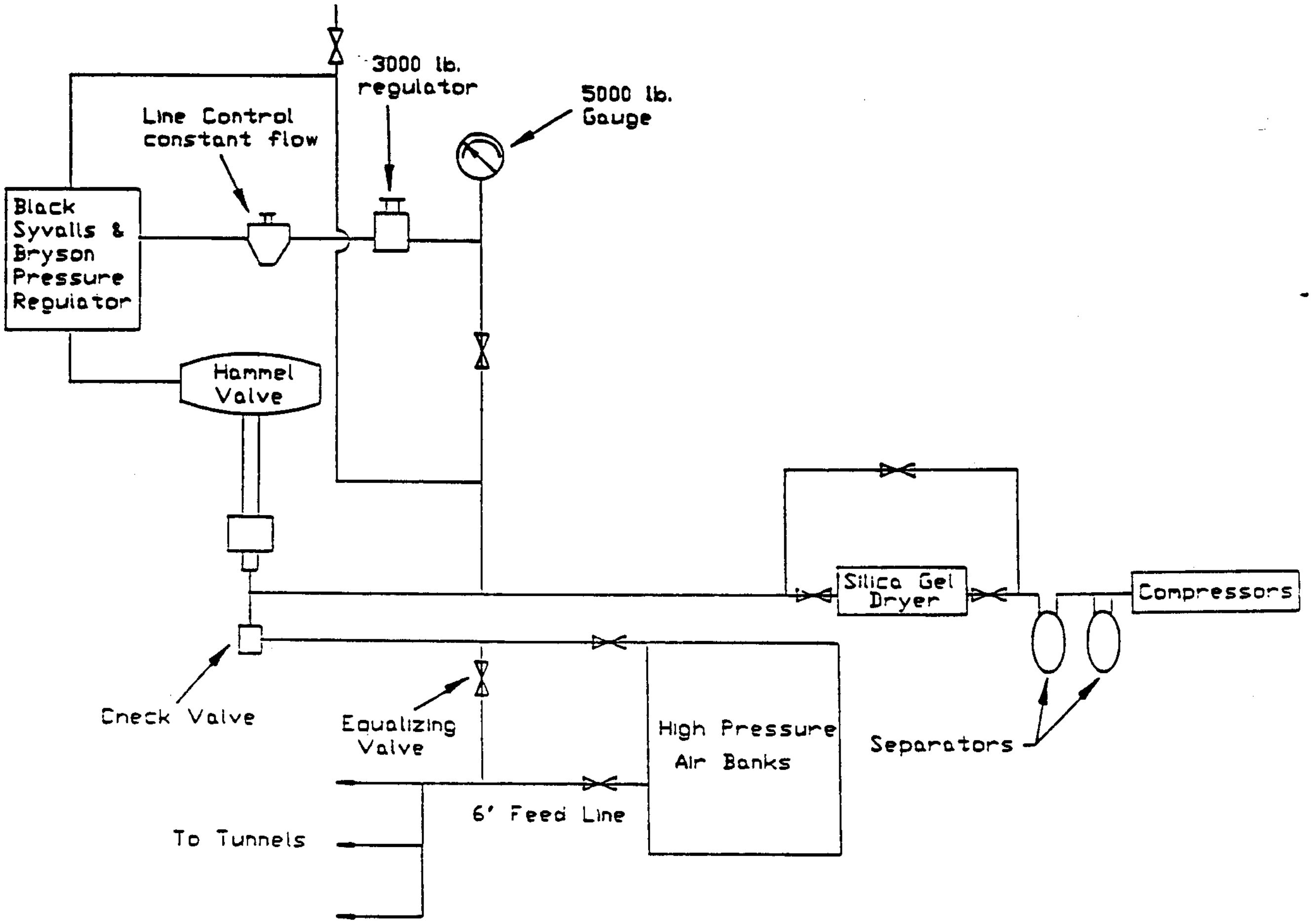


Fig. 6. Schematic diagram of the high pressure pumping, storage and control valves

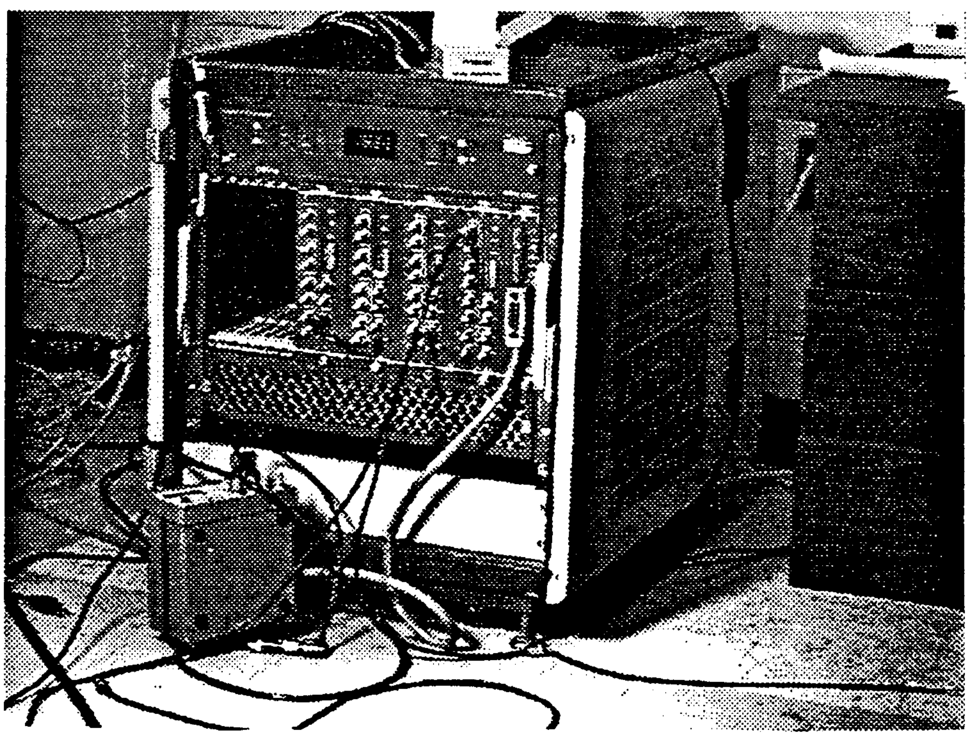


Fig. 7. Photograph of the LeCroy 16-Channel data acquisition system

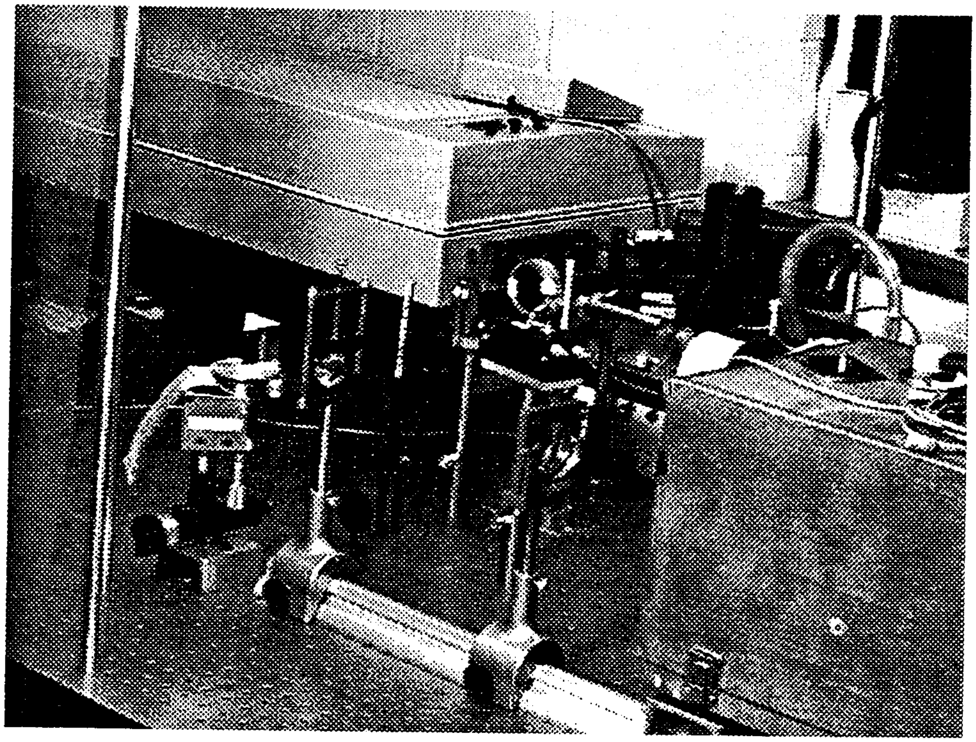


Fig. 8. Photographs of Nd:YAG laser system

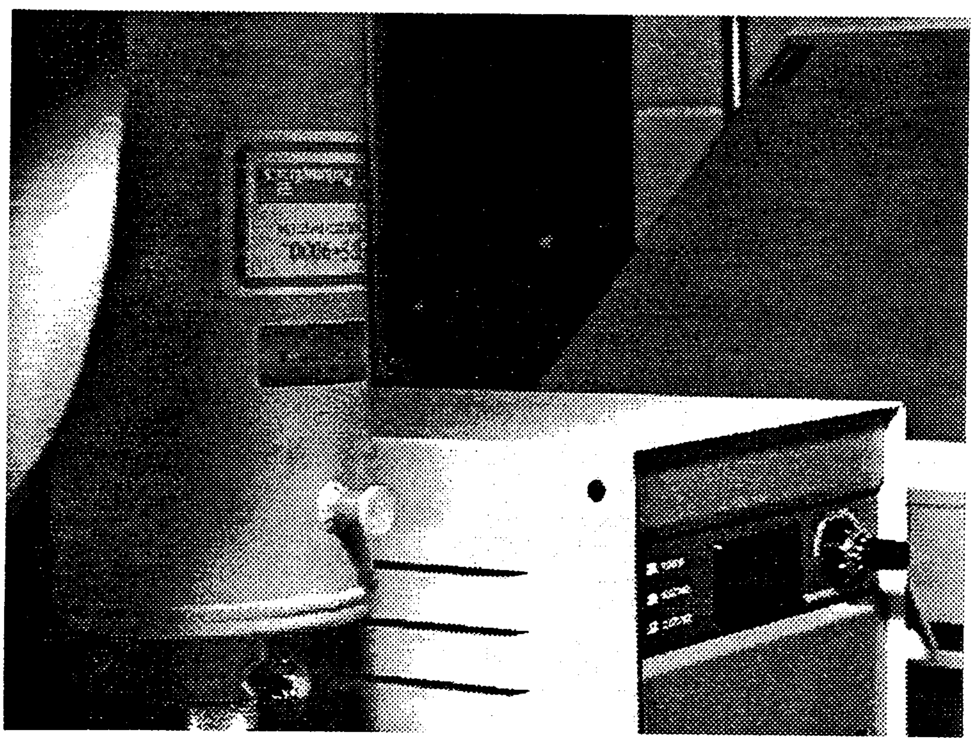


Fig. 9. Photometrics CCD Camera and Controller